PRESSURE CONTROL VALVES

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PLEASE NOTE

Operations personnel use technology to accomplish specific goals. A key objective of the Pipeline Operations Training Program is to promote an understanding of the technology that pipeline operations personnel use on the job every day. This training program enhances job-related skills by providing relevant and current information with immediate application for pipeline employees.

Information contained in the modules is theoretical. A foundation of basic information facilitates an understanding of technology and its applications in the context of a pipeline system. Every effort has been made to reflect pure scientific principles in the training program. **Nevertheless, in some cases, pure theory conflicts with the practical realities of daily operations. Usefulness to the pipeline employee is our most important priority during the development of the materials in the Pipeline Operations Training Program.**

PRESSURE CONTROL VALVES

Pipeline Equipment

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STUDY SKILLS

The following study skill tips are suggested to make the learning of your modules more effective.

1. Try to keep each study period short but concentrated (from ten minutes to forty-five minutes). If you have set up your study time so that you study five days a week for a total of two hours each day, break your study time into sets with two to five minutes between each session. Remember that generally one week of self-study replaces 10 hours of in-class attendance. For example, if you have a three week self-study block, then you have to account for 30 hours of study time if you want to keep pace with most learning programs.

2. When you are studying, look for connections between chapters and tasks. The more connections you can make, the better you will be able to recall information.

3. There are self-tests at the end of each module section. Habitually completing these tests will increase your ability to recall information.

4. When reading a section or module, briefly look it over before you begin detailed reading. Read the introduction, conclusion, and the questions at the end of each section. Next, as a separate task, study all the headings, charts, visuals, and captions. After this excellent preview technique you will be familiar with the skeleton of your reading assignment. The preview reading is then followed by detailed reading. Your detailed reading reinforces what you've already studied and also fleshes out the subject. While you are doing your detailed reading, stop after each sub-section and ask yourself, "What have I just read?"

5. Another useful study technique is to write out your own questions based on your study notes and/or the module's titles and subtitles.

6. When you are in a classroom taking notes, please consider this technique. If you use a standard spiral notebook, write only on the right-hand page. Reserve the left-hand page for your personal observations, ideas, or areas you want to clarify. Importantly, record questions your instructor asks – chances are you'll see them on a final test.

7. Review. Review. Review. Taking opportunities to review material will dramatically increase your recall.

8. Using index cards helps you to quickly pinpoint areas you need to review or concentrate on before an exam. Start by consciously keeping index cards after each reading session. When you come across a new word write it on one side of the index card. On the reverse side, write the definition. It works for every module. For example, chemistry symbol/what it stands for; terminal station/definition; and acronym/what it means. Once you've compiled your index cards and you are preparing for a test, shuffle your index cards with the term word face up. Go through each card to see if you know what is on the reverse side. Why spend unnecessary time on meanings or concepts you know? The cards you don't know, identify areas that you need to review.

9. Additionally, these modules have incorporated specific learning tools to assist comprehension and subject review. Terms are bold-faced and added to the glossary. To cross-reference term meanings, page numbers are attached to glossary definitions to identify where the term and explanation first appear in the text. Glossary definitions that do not have attached page numbers are still important to understanding, but are fully explained in another module.

INTRODUCTION

The correct use and operation of valves is essential to the successful execution of every procedure and maneuver in the pipeline system. The module ISOLATION & SECTIONALIZING VALVES described ON/OFF valves, and specialized valves like check valves, pressure relief valves and stopple fittings. This module looks at pressure control valves (PCVs). These are valves whose construction makes it possible to leave the valve in a partially open position for throttling liquid pressure in the pipeline.

On the pipeline pumps and pressure control valves are the two equipment components used to operate and control the pipeline. The pump is the primary device used to produce pressure and flow. The PCV is used to fine-tune that flow and pressure. Electrically-driven pumps increase pressure in large, fixed-size steps. Often, however, the required pressure is in between these steps. Shutting down a specific pump would leave the pressure too low, while leaving the same pump operating results in a discharge pressure that is too high. To produce the required pressure, operators start pumps to produce a pressure as close as possible but higher than the required pressure. Then a pressure control valve (PCV) is used to "throttle" or reduce the pressure to the required pressure.

When valves are not properly selected and operated, they can be subject to cavitation, rapid wear, and leakage. This will lead to maintenance or replacement sooner than necessary. Closing a control valve too fast can result in severe hydraulic transients. However, effective use of pressure control valves minimizes maintenance problems and the effects of transient waves on the line, and can finely control the liquid flow through the pipeline.

This module discusses the characteristics of pressure control valves, and the basic principles of sizing and selection. Building on the characteristics and principles, the module goes on to discuss the components and operation of pressure control valves and their remotely controlled electrohydraulic actuators showing how these pressure control mechanisms figure in the operators decision-making process.

MODULE GOALS

This module presents information on the following goals.

- It describes the selection criteria for pressure control valves.
- It explains why pressure control devices are critical for safe, efficient pipeline operation.
- It describes common types of pressure control valves.

PREREQUISITES

The modules in the phase Basic Fluid Behavior; ISOLATION & SECTIONALIZING VALVES.

SECTION 1

SIZING & SELECTION OF VALVES

INTRODUCTION

There are many types of valves used in a pipeline system. Each of these valves is selected from the thousands of available valves. Selecting the correct type and size of a valve for each application is a critical part of pipeline design. For example, oversized control valves are difficult to control and require more maintenance than correctly sized valves because they are almost always operated in a near-closed position.

As an operator, you are not directly involved in equipment selection or sizing. However, an understanding of selection and sizing theory will increase your ability to detect abnormal operating conditions, as well as communicate specific problems to engineering and mechanical/electrical staff.

This section provides a brief introduction to some of the important valve characteristics and explains how they relate to the valves chosen for a pipeline system, including consideration of:

- fluid properties
- flow rates
- valve sizing coefficient
- valve type and flow characteristics
- quick open characteristic
- linear characteristic, and
- equal percentage characteristic.

OBJECTIVES

After this section, you will be able to complete the following objectives.

- List three conditions of flow rate that must be taken into account when choosing pressure control valves.
- Recognize the valve sizing coefficient (Cv).
- Explain the function of Cv.
- Identify the quick opening valve characteristic.
- Identify the linear valve characteristic.
- Identify the equal percentage valve characteristic.
- List a requirement for each of the following valve characteristics:
  - maximum pressure drop
  - throttle limitations
  - seat leakage
  - equal percentage, and
  - fail position.

LIQUID PROPERTIES

Key factors in determining which valves should be chosen are the "properties" of the liquids that will be flowing through the valves. Properties of the liquid include:

- whether liquid is corrosive or not
- density
- viscosity
- vapor pressure
- percentage of sediment and water, and
- flow conditioning additives.

In addition, the range of operating temperatures for the pipeline must be established, as the temperature will affect the other properties. Lubricating properties of the liquids handled and the presence of water and abrasive particles in the liquid also influence the choice of control valve type and materials. For a complete explanation of how density, viscosity and vapor pressure influence the behavior of fluid in the pipeline, refer to the training program Introduction to Fluid Behavior.

FLOW RATES

The inter-relationship between liquid properties and flow rates determines how a given liquid will behave at a valve. To ensure a correct valve is chosen, flow rates must be established for five conditions:

- minimum steady-state controlled flow
- maximum steady-state controlled flow
- lowest flow required to recover from a disturbance or upset
- shutdown (no flow), and
- average flow rate.

SIZING

Some engineering standards recommend that the station pressure control valve be sized to a minimum of 5 psi pressure drop and a maximum of 10 psi pressure drop in the full open position at pipeline design capacity flow with the most viscous crude carried in the pipeline.

Some engineering standards also note that when sizing a control valve, the dynamic performance characteristics of the control valve should be considered much more important than a few psi of pressure consumed across an open valve. The pressure drop across a full open control valve is a small percentage of the pressure loss between two pump stations.

The larger the control valve, the further it must be closed to create adequate pressure drop or control. If the pressure control valve is oversized, this results in reduced stability and poor control.

VALVE SIZING CO-EFFICIENT

The valve sizing co-efficient is calculated from the established flow rates discussed above. *The **valve sizing co-efficient (Cv)** is a number equal to the number of gallons (U.S.) of water that will flow through a wide open valve when the pressure differential across the valve is 1 psi and the temperature is at 60°F (15.6°C).* Cv varies with the size and type of the valve, and provides a convenient index for comparing the capacities of different valves under a standard set of conditions.

Valve coefficient values are normally quoted for 100% full open, with individual values for each size. The valve co-efficient varies with the physical size of the valve, the valve design type, and the degree of opening of the valve.

Once the Cv is known, it can be used to calculate the flow rate for any given pressure drop, or the pressure drop for any given flow rate. These calculations are subject to correction, since Cvs are based on test data using water as the flow medium. The higher viscosity of crude oils and petroleum products can result in sizing errors. In applications where the viscosity of the crude is higher than 80 cs, a viscosity correction factor is applied.

The calculated information based on the Cv is used to determine the proper size valve for each application. However, the calculated values represent theoretical models only.

There are subjective elements involved in valve selection as well, including:

- estimated future increases or decreases in throughput
- estimated future changes in the types of crude oils shipped and
- relative costs for different solutions.

It is important to choose valves that are the correct size. An oversized valve can increase maintenance requirements caused by throttling in the near closed position.

VALVE TYPE & FLOW CHARACTERISTICS

Choosing the appropriately sized valve for each application is only the first consideration. The designers must also choose what style of valve to use, and establish the appropriate trim.

Valve trim determines the flow characteristics. Recall from the module ISOLATION AND SECTIONALIZING VALVES that the valve trim consists of the internal, removable parts of the valve. The ***valve flow characteristic*** *of a control valve is the relationship that exists between the travel of the valve and the flow through the valve as the travel is varied from 0% to 100%.* There are three main types of valve flow characteristics:

- quick opening
- linear and
- equal percentage.

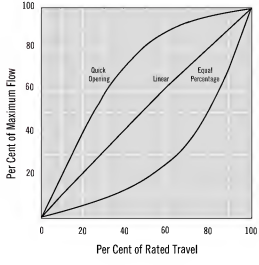


Figure 1
Flow Curves for Valves with Different Flow Characteristics
The quick opening line shows high increase in flow as the valve begins to open. The linear line shows that the increase in flow remains constant across the entire travel of the valve. Finally, the equal percentage line shows maximum decrease in flow as the valve begins to close.

QUICK OPENING

*The **quick opening valve** characteristic provides maximum increase in flow rate as the valve begins to open.* Quick open valves are used for ON/OFF service where flow must be established quickly when the valve begins to open. In Figure 1, the steep slope of the quick open flow curve shows that the valve needs to be only 40% open to establish 75% of maximum flow through the valve.

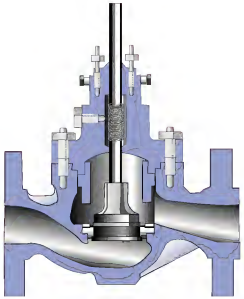


Figure 2
Quick Opening Valve
The round flat disc lifts off a seat ring to expose a cylindrical-shaped opening to the flow. Even a small amount of valve travel results in a large flow area around the circumference of the seat ring and valve plug.

LINEAR

*The **linear valve** characteristic provides equal change in flow rate through its entire travel.* Valves with the linear characteristic are contoured to reduce the quick opening characteristic. Refer again to Figure 1. Notice that the flow curve is relatively straight. When the valve is 30% open, 30% of flow has been re-established; when the valve is 70% open, then approximately 70% of the flow is re-established.

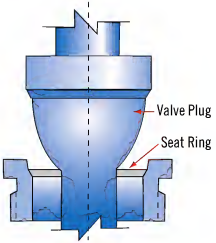


Figure 3
Linear Valve
The tapered shape of the valve plug reduces the quick opening characteristic throughout the full travel of the valve so less flow area per increment of travel is obtained in the flow region. Equal increments of valve travel result in equal increments of flow.

EQUAL PERCENTAGE

*The **equal percentage valve** characteristic provides maximum decrease in flow rate as the valve begins to close*. Ideally, the flow rate should be reduced by 50% by closing the valve only 20% of the way (see Figure 1). On the other hand, as the valve nears the closed position, the rate of change in flow area is much slower than with linear or quick opening valves.

CONSIDERATIONS FOR VALVE REQUIREMENTS

The valves chosen for service in the pipeline system must meet the specifications required by the pipeline's design, such as:

Maximum Pressure Drop - Pressure control valves and actuators must be rated to open or close against a differential pressure equal to the maximum operating pressure.

Throttle Limitations - To avoid cavitation, pressure control valves should never be required to continuously throttle more than 70% of inlet pressure.

Seat Leakage - To reduce the potential severity of pressure transients initiated during valve closure, control valves should not seal bubble tight. Typically, shut-off leakage for globe valves and throttling ball valves must be about 1% of maximum valve capacity. In addition, valve travel has historically been limited to about 95% closure.

Equal Percentage - Pressure Control Valves should have the equal percentage characteristic. Closing the valve 20% from full open (see Figure 1) should reduce the flow through the valve by 50%.

Fail Position - When communications are lost, and if hydraulic pressure drops below a minimum value, the actuator must hold the pressure control valve in the last controlled position.

REVIEW 1

1. *Choice of valves for a pipeline system must take into account the _____ of the liquids to be transported through the pipeline.*
   a) viscosity
   b) density
   c) vapor pressure
   d) all of the above

2. *Station pressure control valves are chosen to provide a pressure drop of 5-10 psi in the full open position at the highest possible flow rate, with the crude oil with the highest _____ in the pipeline.*
   a) density
   b) viscosity
   c) vapor pressure
   d) specific gravity

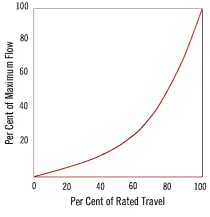
3. *The number equal to the number of gallons (U.S.) of water that will flow through a valve when the pressure differential across the valve is 1 psi at 60°F (15°C) is called the _____ .*
   a) equal percentage
   b) valve sizing co-efficient
   c) index
   d) valve trim

4. *The relationship between valve travel and the flow through the valve is called the valve _____ .*
   a) sizing co-efficient
   b) index
   c) flow characteristic
   d) design

5. *To avoid cavitation, PCVs should never be required to throttle more than _____ of inlet pressure continuously.*
   a) 30%
   b) 50%
   c) 70%
   d) 90%

6. *A quick opening valve characteristic provides _____ .*
   a) maximum increase in flow rate as the valve begins to open
   b) equal change in flow rate through the entire valve travel
   c) minimum increase in the flow rate as the valve begins to open
   d) maximum decrease in the flow rate as the valve begins to close

7. *What flow characteristic is illustrated by this flow curve?*
   a) quick open
   b) linear
   c) equal percentage



Answers are at the end of this module.

SECTION 2

PRESSURE CONTROL VALVES

INTRODUCTION

Pressure control valves are different from ON/OFF valves in that pressure control valves can be left partially open under normal operating conditions. PCVs regulate pressure by changing the size of opening through which the liquids pass. Liquid properties and liquid behavior within a pipeline are discussed in detail in the phase Introduction to Fluid Behavior. For this section, it is important to recall that reducing the flow path causes an increase in flow velocity and a decrease in flow pressure. Enlarging the flow path decreases flow velocity and increases flow pressure. Operators remotely control the PCV so it can accomplish these changes without fully stopping the flow or causing cavitation.

This section will describe the main types of valves used for pressure control, and the benefits and disadvantages of each.

OBJECTIVES

After this section, you will be able to complete the following objectives.

- Identify the function of a pressure control valve.
- Learn the relationship between velocity and pressure.
- Recognize three types of pressure control valves (basic globe valve and its variations, butterfly valve, and throttling ball valve).
- Compare the advantages and disadvantages of each type of pressure control valve.
- List the general characteristics for all pressure control valves.

THROTTLE & THE PRESSURE CONTROL VALVE

The single greatest cost to most pipeline systems is the power used to run main line pump units.

Electrical energy is transformed into mechanical energy, which is in turn converted to pressure by the motor and pump. A pressure control valve is used to throttle pressure to a required level and the energy lost to throttling can never be recovered. Because throttling wastes electrical energy and increases pipeline operating costs, operators should only throttle the amount absolutely necessary to optimize the pipeline system. In addition, reduced throttling minimizes the possibility of damage due to cavitation.

When we refer to pressure control valves (PCVs), we are actually referring to two separate but integral components, the valve itself (including body and trim), and its actuator, the electrohydraulic device that positions the valve.

The function of a control valve is to regulate the flow of a liquid as the position of the valve plug or ball is changed by a force from the actuator. To fulfill the function, the valve body must contain the liquid without leaking, must have adequate capacity, must resist erosion and corrosion, and must be equipped with a movable valve plug or ball that can be positioned properly by the actuator to control the flow.

Typically, in many pipeline systems, PCVs regulate pressures at main line pump stations, restricting flow by use of a ball or plug positioned by an electrohydraulic actuator. PCVs are located at every pump station on the discharge side of the station and are remotely operated by the control center operator.

TYPES OF PRESSURE CONTROL VALVES

There are three types of valves generally used for throttling in pipelines carrying petroleum products:

- globe valve
- butterfly valve, and
- throttling ball valve.

Unlike the ON/OFF valves used for directing the liquid flow, PCV valves are designed to operate when partially open. This means that the size of the valve orifice is varied to accurately control the flow and pressure through the valve.

GLOBE VALVES

*The **globe valve** is so called for the globe shape of the cavity around the port region.* Figure 5 shows a single-ported or straight pattern globe valve. The plug moves up and down to control how much liquid can pass through the orifice. When completely closed, the plug or disc rests on the seat, stopping the flow almost entirely. A problem with globe valves is that sediments tend to gather on the seat, preventing the valve from closing properly. In gathering systems, where the liquids have not yet been treated, sediments could cause problems with globe valves.

The seat of the globe valve is parallel to the direction of flow through the line. This makes the globe valve well-suited for throttling situations because the resistance of flow through a 90° change in direction reduces the pressure. Inside the globe valve, the direction changes four times, allowing for substantial decrease in pressure.

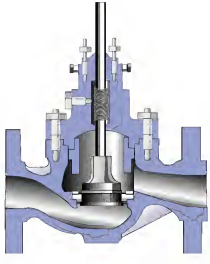


Figure 4
Straight Pattern Globe Valve
Globe valves use a plug or disc resting in the seat to control flow. Globe valves are well suited for pressure control applications because they require liquids to make four turns inside the valve - each turn reducing pressure.

DOUBLE-PORTED GLOBE VALVE

Figure 5 shows a variant of the globe valve - the double-ported globe valve. ***Double-ported globe valves*** *have two plugs arranged so that the flow splits between plug orifices*. The opposing liquid forces across the plug area balance each other, so that a less powerful actuator is needed.

The main advantages of double-ported globe valves are low maintenance and excellent throttling characteristics because of the complex flow path through the valve. These valves are less likely to cavitate than straight pattern globe valves because the complex flow path reduces pressure recovery. Disadvantages of double-ported globe valves are that they are large and heavy, and have lower flow capacity when fully open compared to control valves like the throttling ball valve. In addition, both ports must be mechanically aligned. Wear on one port causes leakage that can only be repaired by machining the valve.

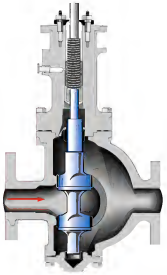


Figure 5
Double-Ported Globe Valve
The two plugs are arranged so that the flow splits with half flowing through each plug orifice. The opposing fluid forces usually balance each other, so that a less powerful actuator is required - allowing a significant saving in power consumption.

BUTTERFLY VALVES

Butterfly valves have a very simple design. *A* ***butterfly valve*** *is a relatively flat, rotating disc mounted on a bearing that allows it to rotate its axis*. When open, the disc offers minimal flow resistance because it is parallel to the direction of flow. When closing, the disc rotates until it is at a right angle to the direction of flow. This allows for a wide range of approximate orifice settings. Butterfly valves are very economical in terms of flow capacity per dollar of investment.

Typically, butterfly valves are used in terminal stations with metering facilities to roughly control and alter flows and pressures into meters and provers.

Figure 6
Butterfly Valve in Open Position
When the butterfly valve is open, it allows little resistance to flow because it is parallel to the direction of flow.

Although butterfly valves do provide throttling control for up to 40% disc rotation, they do not allow for the accurate throttling control of a globe or modified ball valve.

Butterfly valves require only a little more room than the pipe flanges. In fact, wafer butterfly valves are specifically designed for insertion between pipe flanges in existing lines. The full range of motion, from open to closed, is through only a quarter turn (90°). Its simple design makes it one of the least expensive valves available.

The major drawback of the butterfly valve is that, in its simplest form, the absence of any wedging action makes it difficult to completely close. This problem is easily dealt with by seating the disc on a resilient ring seal, which provides sufficient resistance to seal the valve, or by slightly offsetting the disc on the valve spindle so that the disc provides its own wedging action. Using either of these modifications, or both, makes it possible to obtain a tight closure and retain it for a long time before it becomes necessary to replace the seal. ***Seals*** *are a resilient material used to prevent leakage around shafts and past valve internals.*

The butterfly valve does not give the accurate control of a throttling ball valve or globe valve, but it is the least expensive control valve available. Butterfly valves exhibit an approximately equal percentage flow characteristic and provide throttling control for up to 40° disc rotation. Butterfly valves are used in terminals with metering facilities to regulate and alter flows and pressures into the meters and provers for oil measurement purposes. Butterfly valves are controlled or actuated by hydraulic actuators.

Butterfly valves are effective throttling valves, but should not be used for high pressure drop applications because of high operating torque. When throttling at a nearly-closed position, the pressure of the liquid tends to push the valve completely closed, blocking flow altogether.

THROTTLING BALL VALVES

Standard ball valves are discussed in detail in the module ISOLATION & SECTIONALIZING VALVES. They are not normally used for throttling. This is because high velocity flow through a partially opened standard ball valve does not simply pass through the ball, but drives it against the downstream seal. If a standard ball valve is frequently used for throttling, excessive wear on the seal and the ball can result in seat damage and increased maintenance requirements.

*A **throttling ball valve** is a PCV valve that is a partial sphere with a V-shaped fluid flow way. This is a high recovery PCV valve.*

The V-notch throttling ball valve has a spherical housing with a hemispherical closure device as shown in Figure 7. Very low pressure loss is experienced in the full-open position. On the other hand, this valve can be used for high throttling when necessary. Because of the throttling ball valve's flexibility, it is a good choice for crude oil lines where liquids might vary widely in viscosity, and is now the preferred choice for all new PCV installations.

By varying the shape of the V-notch in the ball, most required characteristics can be obtained. For station pressure control service, this characteristic is always "equal percentage".

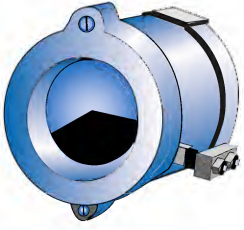


Figure 7
Throttling Ball Valve
The V-notch throttling ball valve has a spherical housing with a hemispherical closure device. This valve allows for straight through flow with very little pressure drop when open.

REVIEW 2

1. *Operators use pressure control valves to regulate line pressure by _____.*
   a) turning them on and off
   b) varying the size of the opening through which the fluids pass
   c) using them to send fluids through lines with different diameters
   d) using them to decrease fluid velocity

2. *A disadvantage of globe valves is that they _____.*
   a) are sensitive to high temperatures
   b) can only achieve a minimal pressure drop
   c) are not well suited for handling solids in suspension
   d) have a direct flow path

3. *Of the valves below, which causes the least resistance to a flowing liquid when completely open?*
   a) straight pattern globe valve
   b) diaphragm valve
   c) butterfly valve
   d) double-ported

4. *Butterfly valves should not be used to throttle liquid in high pressure pipelines because _____.*
   a) they are too difficult to open against high pressure liquid
   b) if they are nearly closed, the liquid pressure pushes them closed
   c) they cavitate too severely
   d) they are designed for ON/OFF applications

Answers are at the end of this module.

SECTION 3

PRESSURE CONTROL VALVE ACTUATORS

INTRODUCTION

On the pipeline valves may be thousands of miles away from the operators who control them. Electrohydraulic actuators receive commands as electronic signals from remote operators. The actuators carry out commands by operating a hydraulic system that controls the pressure control valve (PCV).

The function of the actuator and power unit is to provide valve stroking force in response to an electronic control signal. Electro-hydraulic actuators are used to meet the fine and rapid positioning requirements of a pressure control valve. The electrohydraulic actuator is mounted on the valve and connected by flexible hydraulic hoses to a separate hydraulic power unit which provides the hydraulic fluid pressure to operate the valve. In more recent designs, which are gradually replacing existing units, the hydraulic reservoir and pump are both self-contained and mounted directly with the actuator on the valve.

OBJECTIVES

After this section, you will be able to complete the following objectives.

- Recognize the principle of operation of an electrohydraulic actuator.
- Define the term stroking speed.
- Identify the consequences of large changes in pressure control valve set points.
- Recognize the relationship between manual and remote actuators.

ELECTRO-HYDRAULIC ACTUATORS

The command to open or close the PCV travels to the PLC that controls the valve and is converted into an electronic signal that activates an electrohydraulic actuator. *The **electrohydraulic actuator** converts hydraulic energy into movement of the valve (valve stroke) in response to the electronic signal.* Electrohydraulic actuators are used for rapid, exact positioning of the plug, ball, or disc inside the control valves.

The actuator works together with a controller and a hydraulic power unit. The controller senses and compares the:

- suction set point to the suction pressure, and
- discharge set point to the discharge pressure.

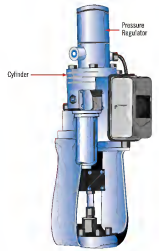


Figure 8
Electrohydraulic Actuator
The hydraulic pressure differential between upper and lower cylinder, maintained according to the pressure regulator (controller), either raises or lowers the valve position, and in so doing, opens or closes the valve.

The controller then responds to the differences between suction and discharge pressure and their respective set points by activating the hydraulic unit to either open or close the valve. The actuator is mounted on the valve and connected by flexible hydraulic hoses to a separate hydraulic power unit. As noted above, more recent units have the hydraulic pump and reservoir mounted directly on the valve. The power unit provides the torque that will eventually be converted into the rotary motion of the ball or disc within the PCV. In globe-type valves, the hydraulic cylinder in the actuator is directly connected to the valve plug.

The cylinder of the actuator is divided by a piston into two parts - upper and lower. A jet activates solenoid valves which direct hydraulic fluid into one or the other section of the cylinder. This causes a pressure differential inside the cylinder. If pressure increases above the piston, the actuator stem moves downward, resulting in valve closure. If pressure increases below the piston, the valve opens.

Changing the discharge set point of a pressure control valve does not mean that discharge pressure immediately changes to the new set point. If you select a 600 psi discharge set point for a PCV whose existing discharge pressure is 615 psi, the actuator will cause the valve to close a little. This may result in an initial new discharge pressure as low as 580 psi. The pressure will eventually adjust to the required 600 psi by means of an internal pressure regulator that re-adjusts the valve position incrementally until a pressure of 600 psi is reached.

STROKING SPEED & DUTY

Stroking speed is the amount of time it takes for the valve to fully open or fully close. The valve stroking speed is usually set at 3 seconds closing and 10 seconds opening. Control valves on manifolds at delivery points have both opening and closing speeds of 10 seconds. Slower closing speeds on manifolds at delivery points reduce pressure surges caused by large controller signal changes in the closed direction. The slower closing speeds may also improve system stability by reducing the tendency to "hunt" for the set point. The hydraulic power unit must be capable of continuous duty in response to 100% control signal changes.

OPERATING CONSIDERATIONS FOR ELECTROHYDRAULIC ACTUATORS

Large set point changes should be avoided. A large set point change sent to a mis-tuned or faulty actuator can cause the valve to oscillate as it attempts to reach the set point too quickly. This results in flow and pressure disturbances down the line. Regular maintenance of the actuator and valve systems will minimize the risk, but applying a series of smaller set point changes to the system, if possible, will minimize the risk of disturbances and minimize wear on the valve-actuator system.

Suppose you select a 500 psi discharge set point, and existing pressure is 550 psi. The valve control signal from the pressure controller will cause the hydraulic unit to supply hydraulic fluid to the actuator to close the valve, resulting in faster valve closure. Although the valve may decrease the pressure to as low as 485 psi, the pressure will eventually adjust itself to 500 psi through internal pressure regulation, such as adjusting the valve position back and forth until the correct setting of 500 psi is established.

EMERGENCY/MANUAL OPERATION

Older remote hydraulic systems have dual pumps to minimize the chance of hydraulic power loss to the PCV. In newer designs, the hydraulic actuator has only a single pump. The pump is always turned on in order to reduce the chance of failure. If a hydraulic power failure does occur, all PCVs are manually operable through the use of hand wheels unless the torque required by the pump is too large to exert manually. When hydraulic power loss occurs, the actuator locks in its last position.

REVIEW 3

1. *The actuators used in most systems to control PCVs are _____.*
   a) pneumatic
   b) electrohydraulic
   c) electronic
   d) manual

2. *When operators want to change a PCV's set point from a remote location, they _____.*
   a) phone a local operator and request the operator to change the set point manually
   b) enter a command into the PCS computer
   c) press the ON button on their keypad
   d) manually turn the flywheel

3. *The controller on the actuator senses and compares the suction set point to the _____.*
   a) suction pressure
   b) last suction set point
   c) discharge pressure
   d) discharge set point

4. *The purpose of the power unit is to _____.*
   a) activate the hydraulic unit
   b) provide a mounting platform for the actuator
   c) direct hydraulic fluid into the top section of the cylinder
   d) provide the torque that moves the disc or ball in the PCV

5. *The term stroking speed refers to the _____.*
   a) number of times a valve can open or close per minute
   b) amount of time it takes for the valve to fully open or fully close
   c) number of cubic meters of fluid that can flow through the valve in one minute
   d) amount of time required to effect a pressure reduction of 43.5 psi (300 kPa)

6. *A mis-tuned or faulty actuator can cause the valve to oscillate in an attempt to reach a new set point too quickly when _____.*
   a) the PCV is almost fully closed
   b) the PCV is almost fully opened
   c) a small set point change is issued
   d) a large set point change is issued

Answers are at the end of this module.

SECTION 4

CONTROL VALVE APPLICATIONS & CONFIGURATIONS

INTRODUCTION

The type and configuration of valves on a pipeline system depends on the application, location, and pressure control requirements for each valve. This section discusses the different pressure control applications in a pipeline system, and how the valves are configured to optimize their effectiveness and make them simple to maintain.

OBJECTIVES

After this section, you will be able to complete the following objectives.

- Recognize the function of pressure control valves (PCVs).
- Identify four specific applications of pressure control valves.
- Recognize the configuration of pressure control valves.
- Differentiate between the control valve/bypass arrangement and the parallel control valve configuration.

PRESSURE CONTROL VALVE APPLICATIONS

At a typical pumping station, pressure control valve (PCV) bodies are usually of double-ported globe, throttling ball or eccentric disc/ butterfly design. Other control valve designs exist but are mostly applied to specific situations such as high pressure or corrosive material handling. PCVs are located at every pump station on the discharge side of the pumps and are remotely operated by the control center operator.

Pressure Control Valves (PCV) *regulate pressures at main line pump stations, restricting flow by use of a ball, plug or disc positioned by an electrohydraulic actuator.*

In the following pipeline system there are four distinct pressure control valve applications:

1. **Pump station pressure control service** - the pressure control valves are located on the discharge side of the station pump units. The valves and related control equipment allow the remote selection and control of upstream suction pressure set points and downstream or discharge pressure set points.

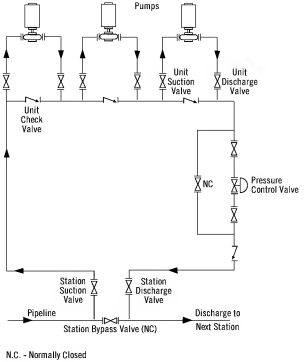


Figure 9
Series Pump Diagram
This diagram shows a basic constant speed pump arrangement in series configuration with suction and discharge pressure controls.

2. **Parallel pump differential pressure control service** - a pressure control valve is located on the discharge side of each parallel pump unit. The valve and related equipment protects the pump and driver from high flow or overload conditions. Differential control is accomplished by monitoring the differential pressure output of the pumps and manipulating the valve to ensure the differential never falls below a specified minimum value, holding the pump within its proper flow range.

3. **Delivery or holding pressure control service** - a pressure control valve is located between the main line and a delivery or terminal location. The valve and related equipment generally allows both pressure protection for the downstream piping of a lower pressure rating and the (optional) remote selection of the upstream main line or holding pressure set point. This application has the highest potential for cavitation due to the very low pressures on the down stream or manifold tankage side of the valve, especially during "strip" or "side stream" deliveries.

4. **Meter manifold back pressure or prover flow control service** - a pressure control valve is located within meter manifold piping downstream of the meters and/or prover. This valve is used to provide the constant back pressure required for standard meter accuracy. Other pressure control valves are installed within the meter and prover piping to provide flow control in the individual meter runs.

CONTROL VALVE CONFIGURATIONS

Each PCV is installed in combination with a fully isolated bypass. This minimizes the impact of valve maintenance and valve failure on the overall efficiency of the line. A pair of gate valves of compatible pressure rating, one upstream and one downstream of the PCV, can be closed to cut off flow through the PCV. To maintain relatively uninterrupted flow through the system, another gate valve can be opened, giving access to the bypass. The bypass itself provides limited pressure regulation as the liquid flows through four right angles.

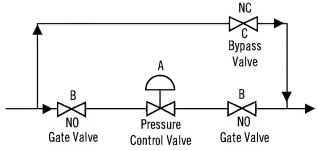


Figure 10
Simple Bypass
The simple bypass shows how the gate valves close on either side of the pressure control valve, isolating it from the liquid flow. The bypass valve opens, allowing the liquid to flow through the bypass.

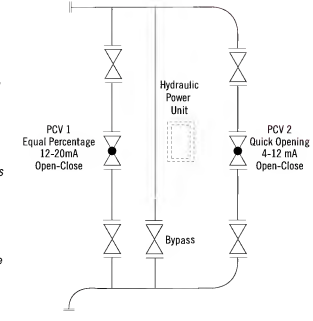
PARALLEL CONTROL VALVES

The parallel PCV configuration consists of a quick opening valve and an equal percentage valve, as shown in Figure 11. The pressure drop across the whole station equals the pressure drop across each of the PCVs. The equal percentage valve produces accurate pressure control, and therefore allows for very accurate control of the pressure drop across the parallel configuration. However, the globe valve causes a large pressure drop due to the complex flow path through the valve. Therefore, the globe valve creates large pressure losses that are not necessarily desired when liquid attempts to flow through the valve at a high rate. If an operator needs high flow rates with a low pressure drop, the quick opening valve is opened. The majority of the liquid flows through the quick opening valve, yet the pressure drop across the whole station is still controlled accurately by the double-ported globe valve. Therefore, the parallel configuration allows for accurate pressure control and large flow rate capacity. Remember though, that the quick opening valve is still capable of controlling the flow, but it does not provide as precise control as the equal percentage valve.

An electronic instrument system detects station pressures and automatically operates control valves to keep within minimum suction pressure and a maximum discharge pressure. Local and remote set points sent by the operator to the pressure control instrumentation cause a milliamp signal to be generated. This is in turn used to move the hydraulically powered control valves to the required positions.

Figure 11
Typical Parallel Valve Configuration

Two pressure transmitters, one measuring suction pressure and the other measuring discharge pressure, send their signals to two controllers. These signals are compared to the operator's set points and the result is sent to a circuit feeding the PCV. The higher signal sent to the override selector is then used to control the station pressure control valve. Parallel control valves operate over a split range. Valve 1 operates from 12 - 20 milliamps; it is fully closed at 20 milliamps and fully open at 12. This valve has an equal percentage characteristic. Valve 2 operates from 4 - 12 milliamps and is fully open at 4 milliamps.



Typically, parallel configuration pressure control systems employ parallel PCVs connected by a single bypass. This allows for more precise pressure control and an uninterrupted flow during maintenance and repair of one or the other parallel valve.

REVIEW 4

1. *The function of a control valve is to regulate the rate of flow of a liquid as the position of the valve plug is changed by a force from the _____.*
   a) button
   b) actuator
   c) fluid flow
   d) pump

2. *The pressure control valves used in a typical station are throttling ball valves and _____.*
   a) butterfly valves
   b) standard globe valves
   c) double-ported globe valves
   d) check valves

3. *At every pump station, PCVs are located on the _____ side of the pump.*
   a) suction
   b) discharge

4. *Which type of pressure control valve service has all of the following characteristics?*
   - The PCV is located between the main line and a terminal location.
   - The valve and related equipment generally allows both pressure protection for the downstream piping of a lower pressure rating and the (optional) remote selection of the upstream main line or holding pressure set point.
   - The application has the highest potential for cavitation due to very low pressures on the downstream side.

   a) pump station pressure control service
   b) parallel pump differential control service
   c) delivery or holding pressure control service
   d) meter manifold back pressure or prover flow service

5. *The total number of valves used in a typical control valve/bypass configuration (including the control valve) is _____.*
   a) 3
   b) 4
   c) 5
   d) 6

Answers are at the end of this module.

SECTION 5

CAVITATION, FLASHING & PRESSURE RECOVERY AT VALVES

INTRODUCTION

The physical phenomena of cavitation and flashing were first introduced in the module VAPOR PRESSURE. This section describes how cavitation and flashing occur in valves, and suggests some operating procedures that will help prevent cavitation and flashing in valves.

OBJECTIVES

After this section, you will be able to complete the following objectives.

- Recognize the causes and results of cavitation at the valves.
- Identify the definition of the *vena contracta*.
- Define the term *flashing*.
- Recognize the causes and results of flashing at valves.
- Differentiate between cavitation, flashing and pressure recovery.
- Identify ways of preventing cavitation and flashing in valves.

CAVITATION

Cavitation *occurs when vapor bubbles produced by a drop in pressure below the vapor pressure of the fluid violently implode when the fluid recovers pressure downstream.* Pressure control valves have ports narrower than the pipeline. Because the ports are narrower, the velocity of the liquid passing through them increases. Pressure drops as velocity increases. If the pressure drops below the vapor pressure of the liquid, some of the liquid will begin to vaporize, and depending on the circumstances, cavitation or flashing will occur.

A valve can be represented by a simple restriction in the line. This is not a perfect representation, but will help us visualize what happens to the liquid pressure and flow rate as the liquid passes through the valve. As liquid flow passes through the restriction, the flow stream narrows. *The minimum cross-sectional area of the flow stream occurs just downstream of the actual restriction at a point called the* ***vena contracta*** *(see Figure 12).*

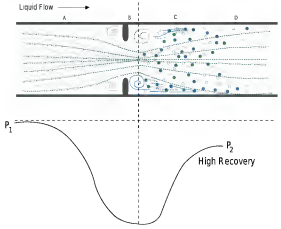


Figure 12
Flow Restriction Showing Vena Contracta
A control valve can be represented by a simple restriction in the line. The vena contracta is the minimum cross-sectional area of the flow stream and occurs a short distance downstream of the physical restriction.

Before we can talk about what happens at the vena contracta, we have to understand the relationship between velocity, pressure, and energy:

- Total energy is "conserved" (remains a constant) and is equal to the amount of kinetic energy + potential energy. Kinetic energy is the energy an object has because it is moving. Potential energy is the amount of energy an object has because of its position (in the sense of elevation or head).
- In a pipeline system, changes in velocity correspond to changes in kinetic energy, while changes in pressure correspond to changes in potential energy.
- Since kinetic energy + potential energy = total energy, if kinetic energy increases, potential energy decreases. Likewise, if potential energy increases, kinetic energy decreases. Changes in velocity and pressure correspond to changes in kinetic and potential energy respectively. Therefore, if velocity of the liquid flow increases, then there is a corresponding decrease in pressure. Conversely, if pressure increases, then velocity decreases.

At the vena contracta, where the cross-sectional area is the smallest, the velocity must be the greatest to maintain a steady flow rate for liquid flowing through the restriction. Since the velocity increases, the pressure at the vena contracta decreases.

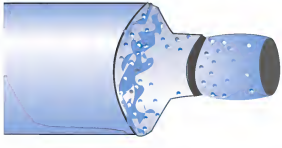


Figure 13
Damage Due to Cavitation
The forces exerted by the tiny implosions of bubbles against metal during cavitation can reach 100,000 psi. No known engineering material can withstand regular cavitation.

Downstream of the restriction, the fluid stream expands into a larger area and slows down. But although slower velocity means a rise in pressure, the downstream pressure never recovers to the pressure that existed upstream of the valve because energy is lost to turbulence and friction in the valve. The pressure dissipated across the valve is a measurement of the amount of energy absorbed by the throttling action. The more energy dissipated in the valve, the greater the pressure differential for the valve. *The **critical pressure differential** is the difference between the pressure at the valve inlet and at the vena contracta.*

Because of increased liquid velocity at the vena contracta, pressure may drop below the liquid's vapor pressure and bubbles may form in the flow stream. The greater the increase in velocity, the greater the drop in pressure.

The entire liquid-vapor-liquid phase change is referred to as cavitation. It is the implosion of the vapor bubbles during pressure recovery that is particularly damaging.

FLASHING

Like cavitation, ***flashing*** *begins with a pressure drop, causing bubbles to form in the liquid. But for flashing to occur, the pressure at the valve outlet remains below the vapor pressure of the liquid, and the bubbles remain in the downstream system.*

Flashing damages the pipeline and valve, scarring surfaces with long smooth scratches that resemble sandblasting. However, if downstream pressure recovery beyond the valve is sufficient to cause the bubbles to implode, cavitation results.

A low recovery valve like a double-ported globe valve would be more inclined to flashing than a high recovery valve like a throttling ball valve. Typically, in large diameter pipelines, cavitation rather than flashing is the more common occurrence. Moreover, flashing is less likely to occur with crude oils and more likely to occur with LPG.

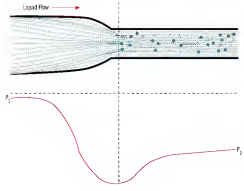
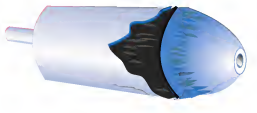


Figure 14
Flashing
Flashing occurs when the pressure downstream of the valve outlet remains below the vapor pressure of the liquid and the bubbles formed by the pressure drop through the valve continue down the pipeline.

Figure 15
Typical Appearance of Flashing Damage
Erosion damage to the plug of a valve. The eroded areas appear as smooth and polished pits and will accumulate at the point of highest velocity.



Clearly, the concept of pressure recovery plays a key role in characterizing a valve's suitability. *A valve that recovers a significant percentage of the pressure differential from inlet to vena contracta is called a* ***high recovery valve****, while a valve that recovers only a small percentage of its pressure differential is called a* ***low recovery valve****.* The throttling ball valve is a high recovery valve, and the globe valve is a low recovery valve.

Figure 14 shows it is not just the condition of cavitation that must be avoided in a valve, but vaporization itself. That is, even though cavitation has not occurred in the low recovery valve, flashing still occurs. The vapor bubbles are still produced at the vena contracta, but they move downstream without the violent imploding caused by pressure recovery. In flashing, the liquid downstream remains partially in the vapor phase.

AVOIDING CAVITATION & FLASHING

Control valves must be sized and selected to avoid the occurrence of cavitation and flashing through the service flow and pressure range. Moreover, there is a significantly increased possibility of flashing and cavitation for delivery or holding pressure applications. High throttle causes flashing and cavitation. Finally, if the potential for cavitation or flashing exists during normal operation, one or more of the following actions should be considered:

1. Special cavitation reducing valve trim (shown in Figure 16). The most common type of cavitation control trim for use in a globe valve is a perforated cage.

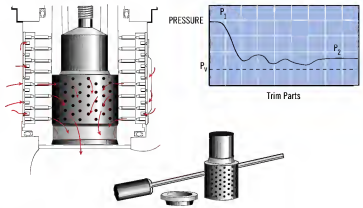


Figure 16
Cavitation Control Cage and Placement in a Globe Valve
Cavitation control cages consist of one or more concentric cylindrical sections. The number of sections, or stages, needed in a cage depends upon the inlet pressure and the pressure drop. The higher these values are for a given valve, the more stages are required. A single-stage cavitation-control cage has diametrically opposite holes that direct streams of cavitating fluid into the center where they impact against each other. This prevents the vapor bubbles from collapsing against the metal surfaces of the valve.

2. Addition of a multi-stage cavitation control cage forces liquid to undergo part of the total pressure drop at each stage. This keeps the liquid pressure from falling below vaporization point at any one stage, completely eliminating cavitation and flashing within the valve.
3. Addition of a second pressure reducing device in series with valve to limit the pressure drop and reduce cavitation potential. The other device might be another valve, reduced piping, or anti-cavitation control valve trim.

The larger the control valve, the further it must be closed to create adequate pressure drop. An oversized valve may frequently be controlling near its fully closed position. This results in reduced stability, possible cavitation, and increased noise.

Excessive vibration through a main line control valve due to cavitation can damage the valve and actuator and may also cause the valve to close.

To avoid cavitation, PCVs should never be required to continuously throttle more than 70% of inlet pressure on individual units. The downstream pressure should always be greater than 30% of the valve inlet pressure.

If cavitation or flashing occurs at a control valve regulating flow into metering devices, measurement will be inaccurate.

REVIEW 5

1. *Cavitation is defined as the _____.*
   a) rapid formation and collapse of vapor pockets in a flowing liquid in regions of low pressure
   b) minimum cross-sectional area of the flow stream at a restriction
   c) amount of energy an object has because of its position
   d) amount of pressure at the vena contracta

2. *If velocity of the liquid flow increases, the pressure _____.*
   a) increases
   b) decreases
   c) fluctuates
   d) is not affected

3. *If cavitation occurs at a control valve regulating flow into metering devices, the measurements will be inaccurate.*
   a) true
   b) false

4. *Which of the following strategies is NOT used to correct cavitation?*
   a) decrease downstream flow rate by transferring some of the throttle to the PCV at the next downstream station
   b) stop the pump unit at the throttling location
   c) decrease the upstream flow rate by transferring some of the throttle to an upstream station
   d) reduce the percentage of set point control at the throttling location

Answers are at the end of this module.

SUMMARY

SECTION 1 - SIZING & SELECTION OF VALVES

- When choosing valves for a pipeline, the projected liquid density, viscosity and vapor pressure, along with the extremes of operating temperature, must be taken into account.
- To ensure a correct valve is chosen, flow rates must be established for minimum steady-state controlled flow, maximum steady state controlled flow, greatest flow required to recover from a disturbance or upset and shutdown (no flow).
- The valve sizing co-efficient (Cv) is a number equal to the number of gallons (U.S.) of water that will flow through a valve when the pressure differential across the valve is 1 psi and the temperature is at 60°F (15°C). Cv varies with the size and type of the valve, and provides a convenient index for comparing the capacities of different valves under a standard set of conditions. Cv must be corrected for high viscosity liquids.
- The quick opening valve characteristic provides maximum increase in flow rate as the valve begins to open. The linear valve characteristic provides equal change in flow rate through its entire travel. The equal percentage valve characteristic provides maximum decrease in flow rate as the valve begins to close.

SECTION 2 - PRESSURE CONTROL VALVES

- Pressure control valves are different from ON/OFF valves in that pressure control valves can be left partially open under normal operating conditions. Pressure control valves (PCVs) regulate pressure by changing the size of opening through which fluids pass.
- The most common types of PCVs are the globe valve, butterfly valve, and modified ball valve.

SECTION 3 - PRESSURE CONTROL VALVE ACTUATORS

- Electrohydraulic actuators provide the force that opens, closes, and holds the positions of PCVs.
- A large set point change sent to a mis-tuned or faulty control valve can cause the valve to oscillate in an attempt to arrive at the desired set point too quickly. This would result in flow and pressure disturbances on the line.
- Stroking speed is the amount of time it takes for the valve to fully open or fully close.
- All PCVs are fitted with manual actuators which make it possible to operate them in the event of mechanical or hydraulic failure.

SECTION 4 - CONTROL VALVE APPLICATIONS & CONFIGURATIONS

- In most pipeline systems, pressure control valves are used for:
  - pump station pressure control
  - parallel pump station differential pressure control
  - delivery or holding pressure control and
  - meter manifold back pressure or prover flow control.
- Each PCV is installed in combination with a fully isolated bypass.
- In some cases, parallel control configurations are used as an alternative to single valve/bypass installations.

SECTION 5 - CAVITATION, FLASHING & PRESSURE RECOVERY AT VALVES

- The entire liquid-vapor-liquid phase change is referred to as cavitation. It is the implosion of the vapor bubbles during pressure recovery that is particularly damaging.
- To avoid cavitation, PCVs should never be required to continuously throttle more than 70% of inlet pressure on individual units.

GLOSSARY

butterfly valve
a relatively flat, rotating disc mounted on a bearing that allows it to rotate its axis. (p. 16)

cavitation
occurs when vapor bubbles produced by a drop in pressure below the vapor pressure of the fluid violently implode when the fluid recovers pressure downstream. (p. 36)

critical pressure differential
is the difference between the pressure at the valve inlet and at the vena contracta. (p. 38)

double-ported globe valves
are arranged so that the flow splits between plug orifices. (p. 16)

electrohydraulic actuator
converts hydraulic energy into movement of the valve (valve stroke) in response to the electronic signal. (p. 22)

equal percentage valve
provides maximum decrease in flow rate as the valve begins to close. (p. 9)

flashing
begins with a pressure drop causing bubbles to form in the liquid. But for flashing to occur, the pressure at the valve outlet remains below the vapor pressure of the liquid and the bubbles remain in the downstream system. (p. 38)

globe valve
a valve with a roughly globe-shaped body, having a flow control element that moves linearly. These are low recovery valves. (p. 15)

high recovery pressure control valve
a valve which recovers a significant percentage of the pressure differential from inlet to the vena contracta. (p. 39)

linear valve
provides equal change in flow rate through its entire travel. (p. 8)

low recovery pressure control valve
a valve that recovers only a small percentage of the pressure differential from inlet to the vena contracta. (p. 39)

pressure control valve
a valve that regulates pressures at main line pump stations, restricting flow by use of a ball or plug positioned by an electrohydraulic actuator. (p. 28)

quick opening valve
a flow characteristic that provides maximum change in flow rate as the valve begins to open, and is used for ON/OFF service where flow must be established quickly when the valve begins to open. (p. 7)

seals
a resilient material used to prevent leakage around shafts and past valve internals. (p. 17)

throttling ball valve
a PCV valve that is a partial sphere with a V-shaped fluid flow way. This is a high recovery PCV valve. (p. 18)

valve flow characteristic
the relationship that exists between flow through the valve and valve travel as the travel is varied from zero to 100%. (p. 7)

valve sizing coefficient (Cv)
Cv is numerically equal to the number of U.S. gallons of water at 60°F (15°C) that will flow through the valve in one minute when the pressure differential across the valve is one pound per square inch. Cv varies with both size and style of valve, but provides an index for comparing liquid capacities of different valves under a standard set of conditions. (p. 6)

vena contracta
the minimum cross-sectional area of the flow stream which occurs a short distance downstream of the physical restriction. (p. 36)

ANSWERS

REVIEW 1	REVIEW 2	REVIEW 3	REVIEW 4	REVIEW 5
1. d	1. b	1. b	1. b	1. a
2. b	2. c	2. b	2. c	2. b
3. b	3. c	3. a	3. b	3. a
4. c	4. b	4. d	4. c	4. c
5. c		5. b	5. b	
6. a		6. d		
7. c				